Comments on: "Can existing theory predict the response of tropical cyclone intensity to idealized landfall?" by Jie Chen and Daniel R. Chavas

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In their paper, Chen and Chavas (2021) (henceforth CC21) test both the steady-state intensity theory of Emanuel (1986) and "the time-dependent intensity change theory of (E12) (Emanuel 2012, our insertion) against sets of simulations where surface roughness and wetness are individually or simultaneously modified instantaneously beneath a mature axisymmetric tropical cyclone". The paper builds on an earlier study by Chen and Chavas (2020) using the E12 theory in which vortex spin up is hypothesized to be controlled by turbulent mixing in the upper-tropospheric outflow layer. Two main conclusions are that " ... the theory is shown to compare well with the prevailing empirical decay model for real-world storms" and "Overall, results indicate the potential for existing theory to predict how tropical cyclone intensity evolves after landfall". These conclusions may be interpreted as a strong endorsement of the theory and was a surprise to us in the light of our earlier analysis of the same theory (Montgomery and Smith 2019). This analysis showed that the physics of how upper-tropospheric mixing in the outflow layer leads to vortex spin up, in or at the top of the friction layer, is unclear, but irrelevant to spin up in the model. We wonder if CC21 have a new explanation for the inner-core physics embodied in the E12 model that transcends our own analysis and justifies their extension of the model? We are curious to know, in particular, how they justify the assumption that the surfaces of absolute angular momentum and saturation moist entropy remain congruent, implying convective neutrality at all times during the decay of the vortex over land?

An intriguing feature of the analytical solution derived by CC21 in their appendix is that the crucial effects of turbulent mixing represented by the second term on the right hand side of Eq. (16) in the original E12 theory have disappeared for the landfall problem. In particular, the parameterization of upper-tropospheric turbulent mixing in the original theory introduces the parameter r_t in the tendency equation for the gradient wind. The parameter r_t denotes the radius where the gradient Richardson number first becomes critical. This radius is unknown a priori and is not determined by the theory, but must be prescribed. Since the positive term in the resulting tendency equation for the gradient wind predicted by the theory is inversely proportional to r_t^2, it represents a potentially sensitive dependence of the landfall solution on this unknown radius. However, the inverse square dependence on r_t has disappeared in the CC21 formulation without comment.

CC21 carry out a series of calculations with their extended theory using a range of boundary layer depths h, but seem to favor the choice $h = 5$ km used by E12 as the "correct" boundary layer depth in a hurricane vortex. Their defense of the choice of $h = 5$ km (p3284) seems questionable to us, essentially arguing that 5 km is a compromise between a much smaller boundary layer value and the near tropopause height where deep cumulus convection in the eyewall detrains. The spin up rate in the Emanuel (and CC21) theory varies as the inverse of this boundary layer depth (see Eq. (17) of E12 and Eq. (A1) of CC21) so one can expect (and CC21 confirm in their Fig. 1b and elsewhere) a strong sensitivity of the predicted spin up or spin down of the vortex with the boundary layer depth. Observations of Zhang et al. (2011) show that $h = 750$ m is the appropriate dynamical boundary layer depth of a hurricane in the high wind region of the vortex (their Fig. 10, top row, all hurricanes). An unrealistic 5 km boundary layer depth implies a theoretical spin up/spin down rate that is roughly 5 times smaller than what the basic or modified theory would predict using a realistic boundary layer depth of $h \approx 1$ km! This fact reinforces legitimate concerns we have about the validity of the E12 theory as well as CC21's choice to essentially stand behind the Emanuel value of $h = 5$ km (p3292). This is another puzzling feature of CC21's extended theory.

Acknowledgments.

MTM acknowledges the support of the National Science Foundation, the Office of Naval Research and the U.S. Naval Postgraduate School.

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